# Effects of Supplementation of Fertilizers on Human Selenium Status in Finland*

**Antti Aro and Georg Alfthan**

*Department of Nutrition, National Public Health Institute, Mannerheimintie 166, FIN-00300 Helsinki, Finland*

**Pertti Varo**

*Department of Applied Chemistry and Microbiology, University of Helsinki, FIN-00710 Helsinki, Finland*



**The Se concentration of foods can be increased by supplementing fertilizers with soluble Se compounds. In Finland the availability of soil Se for plants is poor owing to the relatively low Se concentration, low pH and high iron content of the soil. Since 1984 multimineral fertilizers have been supplemented with Se (16 mg $kg^{-1}$ to fertilizers for grain production and 6 mg $kg^{-1}$ to those for fodder production) in the form of sodium selenate. Within two years a three-fold increase of mean Se intake was observed. The supplementation affected the Se content of all major food groups with the exception of fish. The concomitant human serum Se concentration increased by 70%. In 1990 the amount of Se that was supplemented was reduced to 6 mg $kg^{-1}$ for all fertilizers. This reduced the mean Se intake by 30% and the serum Se concentration decreased by 25% from the highest levels observed in 1989. Plants take up part of the supplemented selenate and transform it into organic Se compounds, mainly selenomethionine. This affects human nutrition by increasing the Se content of foods of both animal and vegetable origin. According to data obtained in Finland, supplementation of fertilizers with Se is a safe and effective means of increasing the Se intake of both animals and humans that is feasible in countries with relatively uniform geochemical conditions. This kind of intervention requires careful monitoring of the effects on both animal and human nutrition and the environment.**

***Keywords:*** *Selenium; fertilization; human; intake; nutrition*

## Introduction

The Se content of foods is low in areas where the Se concentration in soils is low or where Se exists in chemical forms that are not readily available for plants. Selenates are generally water-soluble and form soluble adsorption complexes whereas selenites are mostly insoluble. In alkaline soils and under aerobic conditions Se exists mostly in the form of selenates that are readily available for plants.[1] In soils with a low pH and high humidity reduced forms of Se are found such as selenites and selenides, which form insoluble complexes with iron(III) and aluminium compounds.[2] This is a condition typical of Finland where only about 5% of total Se in soils is in a soluble form and available for plants.[3] In studies conducted in Finland in the 1970s, low Se concentrations were found in locally produced foods, and the total human Se intake was estimated to be only about 25 μg $d^{-1}$.[4]

## Effects of Se Defficiency

In certain areas of the People's Republic of China Se intake is extremely low, around or below 10 μg $d^{-1}$. In this area an endemic, often fatal cardiomyopathy affects the population, particularly children and young women. The disorder, Keshan disease, can be prevented by prophylactic administration of sodium selenite.[5] It is assumed that the condition is caused by deficiency in Se, possibly combined with a viral infection or other nutritional factors.

There is no direct evidence of the harmful health effects of a mild Se defficiency. Nevertheless, epidemiological evidence exists suggesting that low Se intakes, reflected in low serum Se levels, may increase the risk of cardiovascular disease and cancer.[6] In prospective case-control studies from Finland[7] and Denmark[8] an increased risk of cardiovascular death or ischemic heart disease was observed in men whose serum Se values were within the lowest tertile of the distributions within respective populations. No such association has been evident in populations where low serum selenium values are rare or non-existing.[6] With respect to cancer, studies from Finland and the USA have suggested that the risk of certain types of cancer, *i.e.*, that of upper gastrointestinal tract and the lung, is increased in men but not in women.[9,10] However, in several studies, most of them from the USA, no association has been found between serum Se and the risk of cancer.[6]

## Supplementation of Fertilizers in Finland

Being aware of the low Se intake of the Finnish population and the suggestions about its possible harmful health effects, the Ministry of Agriculture and Forestry of Finland decided in 1984 to start supplementation of fertilizers with Se.[11] The decision was based on information from Denmark and Finland indicating that supplementary selenate, in contrast to selenite, stays in the soil in a form that is available for plants for several months.[12,13] It was also known that the amount of selenate that was necessary to increase the Se content of grass was smaller than the amount needed for increasing the Se concentration of grains.[13] The amount of Se added to fertilizers for grain production was 16 mg $kg^{-1}$ and that added to fertilizers for the production of hay and fodder was 6 mg $kg^{-1}$ corresponding, on average, to 8 g $ha^{-1}$ for cereals and 3 g $ha^{-1}$ for pastures annually. Although Se is not an essential element for plants, they take up the mineral and incorporate it into organic compounds. Therefore, it was predicted that the supplementation of fertilizers with selenate would affect the Se content of foods both from the vegetable kingdom and of animal origin.

An expert group was appointed by the Ministry of Agriculture and Forestry to monitor the effects of Se supplementation

* Presented at The Fifth Nordic Symposium on Trace Elements in Human Health and Disease, Loen, Norway, June 19–22, 1994.

of fertilizers on soils and waters, fertilizers, animal feeds, foods and human Se status, and to give annual statements on the situation. The amounts of Se added to fertilizers were kept constant until 1990 when it was decided to reduce the supplement to 6 mg $kg^{-1}$ for all fertilizers.[11]

## Effects on Human Nutrition

Since 1969, animal feeds have been enriched with selenite in Finland. This practice had very little effect on the Se intake of people which remained low throughout the 1970s. Serum Se concentrations of healthy people were around 50–60 μg $l^{-1}$.[14] In 1979 and 1982 there were poor domestic crops and high-Se wheat was imported from the USA. This resulted in considerable fluctuations in the Se intake of people and between 1980 and 1984 the mean serum Se concentrations showed annual variations between 70 and 100 μg $l^{-1}$.[14]

When the effects of Se supplementation became evident in 1985, milk was the first food item that showed an almost immediate increase in Se content. This was followed by meat products, cereal products and other dairy products within a period of 6 months.[15] The mean Se intake was increased by 2 to 3-fold during the first year, and during the subsequent 3 years the intake was stabilized at a level of 110–120 μg per 10 MJ.[11,15] The impact of meat products increased most, to more than 40% of total Se intake, followed by that of dairy products (25%) and cereal products (20%). Selenium intake from fish remained quantitatively unchanged but its share of the total Se intake declined from 30% before Se supplementation to less than 10% afterwards[11] (Fig. 1).

The serum Se concentrations of a small reference group of healthy individuals have been monitored since the mid 1970s.[14] In 1985 this group, consisting of urban people from Helsinki, was expanded by recruiting another group of healthy individuals (from a rural area), mainly members of farming families from central Finland. The concomitant serum Se concentrations of both groups increased from levels of 65–70 μg $l^{-1}$ in 1985 to 120 μg $l^{-1}$ in 1989–1991 (Fig. 2). Similar effects were also observed in other groups of people including children, adults, elderly men and women, and pregnant women.[11]

After 1990, because of the reduction in the amount of Se supplemented to fertilizers, the mean Se intake was reduced gradually to 85 μg per 10 MJ in 1993 (Fig. 1). A concomitant decline was observed in the mean serum Se concentrations to the level of 100 μg $l^{-1}$ in both reference groups of healthy subjects (Fig. 2).

Selenocysteine is an integral part of the enzyme glutathione peroxidase (GSHPx) which catalyses the reduction of hydrogen peroxide to water and fatty acid hydroperoxides to their respective alcohols. GSHPx activity is dependent on Se intake up to a certain saturation level, which is different for different tissues: relatively low (about 40 μg $d^{-1}$) for serum and higher (about 120 μg $d^{-1}$) for platelets.[16] When a group of healthy Finnish men was supplemented with 200 μg $d^{-1}$ of Se, in 1981 before the supplementation period, platelet GSHPx activity was doubled.[17] In a similar supplementation study (with the same men) in 1988, the GSHPx activity was increased only by 0–30% by different Se compounds showing that the increased Se intake had stimulated the GSHPx activity in platelets to near-maximal levels.[16] GSHPx activity in serum did not respond to supplementation levels in either study.

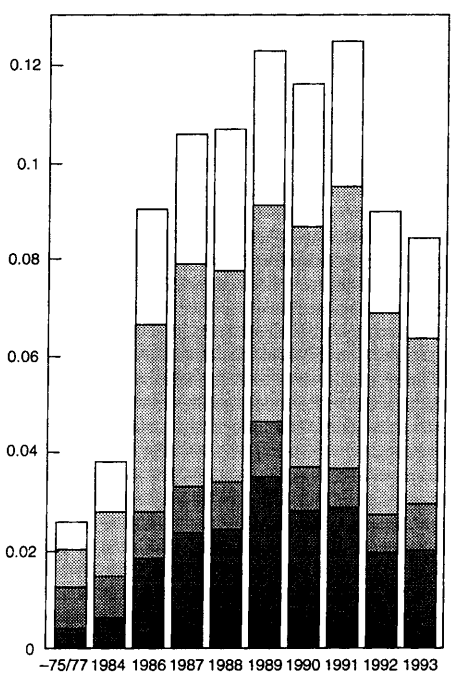


**Fig. 1** Selenium intake mg $d^{-1}$ from different foods in Finland before and during supplementation of fertilizers with sodium selenate, based on an energy intake of 10 MJ $d^{-1}$. Se supplementation was started in 1985, and the amount was reduced in 1991: □, milk; ▒, meat; ▩, fish; ■, cereal; ■, vegetables; and ■, other.

## Conclusions

Supplementation of fertilizers with Se as sodium selenate has been successful in increasing the Se intake of people in Finland. It has increased the Se content of most foods, particularly that of meat, dairy, and cereal products. Human serum Se concentrations have been almost doubled and the activity of GSHPx in blood platelets has been increased to near-maximal levels. In addition, the supplementation has reduced the need to supplement animal feeds with inorganic Se. Plants transform the selenate that they uptake into organic Se compounds. This increases animal intake of organic Se, which is incorporated in tissues, and increases the Se content of meat, eggs, and milk; all important constituents of the human diet. The experiment has shown that it is possible to modify the Se intake of a population and to bring it to the appropriate level by adjusting the amount of supplementary Se. Supplementation of fertilizers with Se is feasible in countries with relatively uniform geochemical conditions. Careful planning and close monitoring of the effects on animal and human nutrition and the environment are necessary if fertilizers are supplemented with Se. Simple supplementation

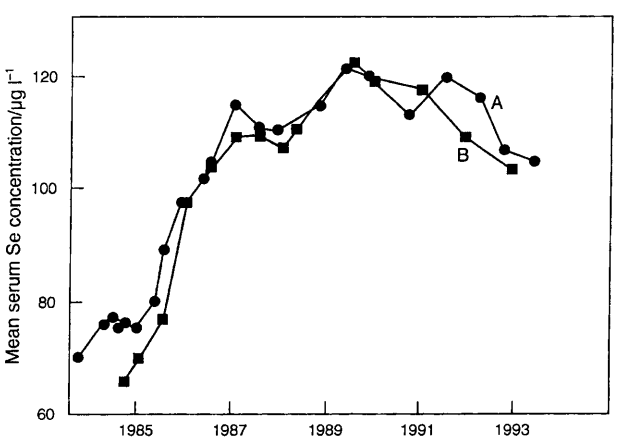


**Fig. 2** Mean serum Se concentrations of A, healthy urban (Helsinki) and B, rural (Leppävirta) people in Finland between 1985 and 1993. Se supplementation was started in 1985, and the amount was reduced in 1991. To convert μg $l^{-1}$ into μmol $l^{-1}$, divide by 78.96.

of animal feeds with organic Se is an alternative approach, which may be an easier way of improving human Se nutrition, for some countries with low dietary Se intakes.

## References


1 Fan, A. M., Book, S. A., Neutra, R. R., and Epstein, D. M., *J. Toxicol. Environ. Health,* 1988, **23**, 539.
2 Combs, G. F., and Combs, S. B., *The Role of Selenium in Nutrition*, Academic Press, New York, 1986.
3 Sippola, J., *Ann. Agric. Fenn.,* 1979, **18**, 182.
4 Varo, P., and Koivistoinen, P., *Acta Agric. Scand.,* 1980, **22** (suppl), 165.
5 Chen, X., Yang, G., Chen, J., Chen, X., Wen, Z., and Gen, K., *Biol. Trace Elem. Res.,* 1980, **2**, 91.
6 Aro, A., *Norw. J. Agric. Sci.*, 1993, **11** (suppl), 127.
7 Salonen, J. T., Alfthan, G., Pikkarainen, J., Huttunen, J. K., and Puska, P., *Lancet*, 1982, **2**, 175.
8 Suadicani, P., Hein, H. O., and Gyntelberg, F., *Atherosclerosis*, 1992, **96**, 33.
9 Knekt, P., Aromaa, A., Maatela, J., Alfthan, G., Aaran, R.-K., Hakama, M., Hakulinen, T., Peto, R., and Teppo, L., *J. Natl. Cancer Inst.,* 1990, **82**, 864.
10 Willett, W. C., Stampfer, M. J., Hunter, D., and Colditz, G. A., in *Trace Elements in Health and Disease,* ed. Aitio, A., Aro, A., Järvisalo, J., and Vainio, H., The Royal Society of Chemistry, Cambridge, 1991, pp. 141–155.
11 Varo, P., Alfthan, G., Huttunen, J. K., and Aro, A., in *Selenium in Biology and Human Health*, ed. Burk, R. F., Springer, New York, 1994, pp. 198–218.
12 Gissel-Nielsen, G., and Bisbjerg, B., *Plant Soil,* 1970, **32**, 382.
13 Yläranta, T., *Increasing the Selenium Content of Cereal and Grass Crops in Finland,* University of Helsinki, Helsinki, 1985.
14 Alfthan, G., *Nutr. Res.,* 1988, **8**, 467.
15 Varo, P., Alfthan, G., Ekholm, P., Aro, A., and Koivistoinen, P., *Am. J. Clin. Nutr.,* 1988, **48**, 324.
16 Alfthan, G., Aro, A., Arvilommi, H., and Huttunen, J. K., *Am. J. Clin. Nutr.,* 1991, **53**, 120.
17 Levander, O. A., Alfthan, G., Arvilommi, H., Gref, C.-G., Huttunen, J. K., Kataja, M., Koivistoinen, P., and Pikkarainen, J., *Am. J. Clin. Nutr.*, 1983, **37**, 887.


*Paper 4/03956D*
*Received June 29, 1994*
*Accepted August 5, 1994*